Mixed Fuel versus Low Enriched Fuel in the Syrian MNSR

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Abstract:

A study of the Syrian MNSR in both cases when only a LEU is used in the reactor, and when both LEU and HEU are simultaneously used is done in this paper. Some of the reactor neutronic and thermal-hydraulic characteristics in the two cases are compared and commented.
Some other important features of the reactor are emphasized as well.

KEYWORDS
Reactor, MNSR, Comparison, LEU, HEU, Fuel.

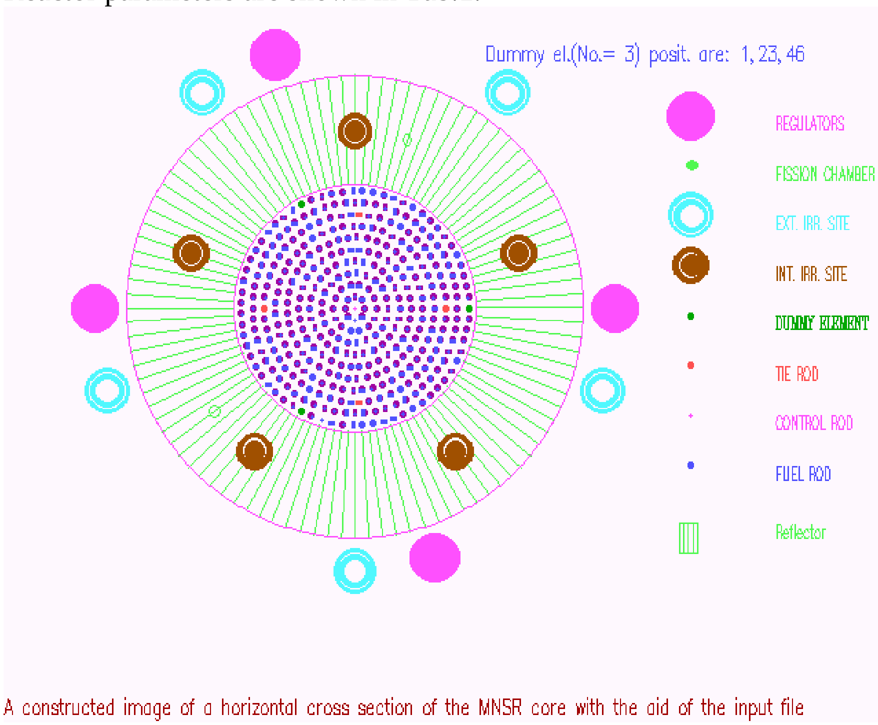
1.Introduction

The knowledge of the characteristics of the Syrian MNSR is very important since it is determinant for the selection of the type of fuel to be used in this reactor. The types of fuels which are based on the dispersion of the fuel particles in a matrix of Al alloys has been investigated in earlier works [1, 2]. It has been demonstrated that the reactor can be made critical using well-known LEU types of fuels such as UAl_2-Al_x and UAl_3-Al_x dispersions by utilizing the good savings of the reflector of this reactor. It should be reminded here that the possibility of rendering the reactor critical relies also on the assumption that the material composition of the reflector can be selected from the available impure compositions.
It was proved also that the reflector composition is very important in this type of reactors. The challenge which was overcome in [1] was that the reactor remained to be critical meanwhile using dispersion type fuel (like the one actually used in the reactor).This was achievable partly because of the assumed possibility of susbstituting the annular reflector material with the base reflector material. The same applies for the Top Beryllium Reflector material. This solution implies really the changing of the reflector and the fuel itself as dimensions and composition, but not the type of fuel.
In this paper there is an attempt to conserve the actual fuel structure (dimensions), but keeping a certain number of the old HEU fuel rods in the core of the reactor, and seeing if this would have any influence on the thermal hydraulic characteristics of the reactor.

2.Importance of the fuel location in the core of the Reactor

2.1- The case of UAl3-Alx

The importance of the fuel will depend certainly on the location of the fuel rods in the core of the reactor. This is partially due to the different flux levels in the core, and partially is due to the different average temperatures in the different channels of the core. We shall compare the new core configuration parameters of the reactor with the normal (reference) case (see Fig.1). The following study will show how the importance of the fuel could determine how to use it in the reactor. The reference Reactor parameters are shown in Tab.1.



Figure(1) A schematic cross section of the Syrian MNSR.

The first column enumerates the fuel circles (10 circles, or equivalently the coolant channels. The second column describes the type of fuel used in the circle. The

Tab.1 The Reference Reactor Parameters and characteristics

Fuel Circle No.	Fuel mat. No.		Thermal Power (w)		$\frac{P_{ref} - P_1}{P_{ref}}$ (%)	Max. Temp. In Ch. (ºC)		Initial excess reactivity (mk)		Top Ref. Mat.		Annulus Refl. Mat.		Top Ref. Thickness (cm)	
	Ref. C.	C1	Ref. C.	C-1		Ref C.	C-1	Ref C.	C-1	Ref. C.	C-1	Ref C.	C-1	Ref. .C	C-1
1	4	4	528.97	549.789	-3.935	54.37	53.87	27.0556	3.9057	17	5	14	5	14.2	5.85
2	4	3	1160.90	512.0961	5.54	55.90	5.29								
3	4	4	1725.01	6240.318	-6.10	55.	55.01								
4	4	3	2302.18	080.7621	5.477	54.72	54.92								
5	4	4	2771.29	692.4729	-6.35	54.43	54.49								
6	4	3	3335.52	3154.346	5.43	54.17	54.35								
7	4	4	3780.83	4028.995	-6.56	53.70	53.34								
8	4	3	4225.99	3994.559	5.47	54.08	54.35								
9	4	4	5035.83	5397.292	-7.17	53.04	53.11								
10	4	3	4754.445	4421.221	7.00	49.41	48.44								

number 4 denotes the original fuel type(UAl_4-Al alloy), while 3 stands for the UAl_3-Al_x type. The first case for which calculations are made is the case in which circles are filled alternatively with the 4 and 3 fuel types, respectively.

Only in the reference case, the Top and the Annulus reflector materials are the actually used ones in the reactor (Materials 17 and 14 respectively).
Calculations are made using both the cell code WIMSD4 [3] and the 3-D code CITATION [4]. The neutronic model was previously established [5], and the thermohydraulic code HYDMN[6] was used to make the hot channel analysis of the core.l
Note that the configuration of case-1 for the core does not lead to a critical reactor if the actual materials for Top and Annulus reflectors materials are used, even if the upper Shim Tray is completely filled with the Top Beryllium Shims (14.2 cm).
This configuration for the core implies the presence of 160 fuel rods of the type 4 and 187 ones of the type 3.
It can be shown that the best utilization of the fuel is achieved when the higher enriched fuel is used in the central zone of the core and the lesser enriched one is uesd in the peripherical region. (see Tab. 2)

Tab.2 The Case when HEU is utilized in the center of the core.

Fuel Circle No.	Fuel mat. No.		**Thermal Power (w)**		$\frac{P_{ref}-P_1}{P_{ref}}$ (%)	Max. Temp. In Ch. (ºC)		Initial excess reactivity (mk)(*)		Top Ref. Mat.(**)		Annulus Refl. Mat.(**)		Top Ref. Thickness (cm)	
	Ref. C.	C 2	Ref. C.	C-2		Ref C.	C-2	Ref C.	C-2	Ref. C.	C-2	Ref C.	C-2	Ref. .C	C-2
1	4	4	528.97	547.016	-3.411	54.37	53.87	27.0556	3.7807	17	5	14	5	14.2	6.8
2	4	4	1160.90	1200.8	-3.437	55.90	55.28								
3	4	4	1725.01	1785.491	-3.506	55.	55.01								
4	4	4	2302.18	2386.243	-3.651	54.72	54.92								
5	4	4	2771.29	2880.785	-3.951	54.43	54.42								
6	4	4	3335.52	3486.050	-4.513	54.17	54.35								
7	4	4	3780.83	3989.942	-5.530	53.70	53.74								
8	4	4	4225.99	4391.333	-3.912	54.08	54.35								
9	4	3	5035.83	4594.747	8.759	53.04	53.11								
10	4	3	4754.445	4350.578	8.494	49.41	48.44								

In this case (Case 2) we have 120 LEU rods versus 227 rods of the HEU type. The reactor is critical with the only 6.8 cm thickness of the Top Beryllium Shims. If 14.2 cm of Top Beryllium Shims were used, the reactor could go critical with 144 LEU fuel rods and 203 HEU fuel rods.

2.1- The case of UAl_2-Al_x

The same conclusions apply here for what concerns the importance of the position of the fuel in the core. But since the UAl_2-Al_x fuel is denser than the UAl_3-Al_x [7], it is expected that the reactor can work with more rods of the LEU type and less rods of the HEU type. In fact calculations show (see Tab. 3) that the reactor can keep almost the same initial excess reactivity with 285 LEU rods used in the outer 5 fuel circles, and only 62 rods of the type HEU in the first 5 fuel circles.
In this case the thickness of the Top Beryllium Reflector is maximum (14.2 cm).
These numbers constitute the limits, from the neutronics point of view, where the reactor can go critical with fresh fuel.

Tab.3 The Case of UAl_2-Al_x

Fuel Circle No.	Fuel mat. No.		Thermal Power (w)		$\frac{P_{ref}-P_1}{P_{ref}}$ (%)	Max. Temp. In Ch. (ºC)		Initial excess reactivity (mk)(*)		Top Ref. Mat.(**)		Annulus Refl. Mat.(**)		Top Ref. Thickness (cm)	
	Ref. C.	C3	Ref. C.	C-3		Ref C.	C-3	Ref C.	C-3	Ref. C.	C-3	Ref C.	C-3	Ref. .C	C-3
1	4	4	528.97	543.23	-2.696	54.37	54.90	27.0556	4.8167	17	5	14	5	14.2	14.2
2	4	4	1160.90	1193.52	-3.437	55.90	55.58								
3	4	4	1725.01	1777.62	-2.809	55.	55.77								
4	4	4	2302.18	2381.99	-3.466	54.72	55.36								
5	4	4	2771.29	2856.39	-3.070	54.43	54.69								
6	4	4	3335.52	3331.68	0.115	54.17	54.57								
7	4	4	3780.83	3934.37	-4.061	53.70	53.86								
8	4	4	4225.99	4139.69	2.042	54.08	53.27								
9	4	3	5035.83	4722.92	6.214	53.04	52.45								
10	4	3	4754.445	4732.43	0.046	49.41	49.37								

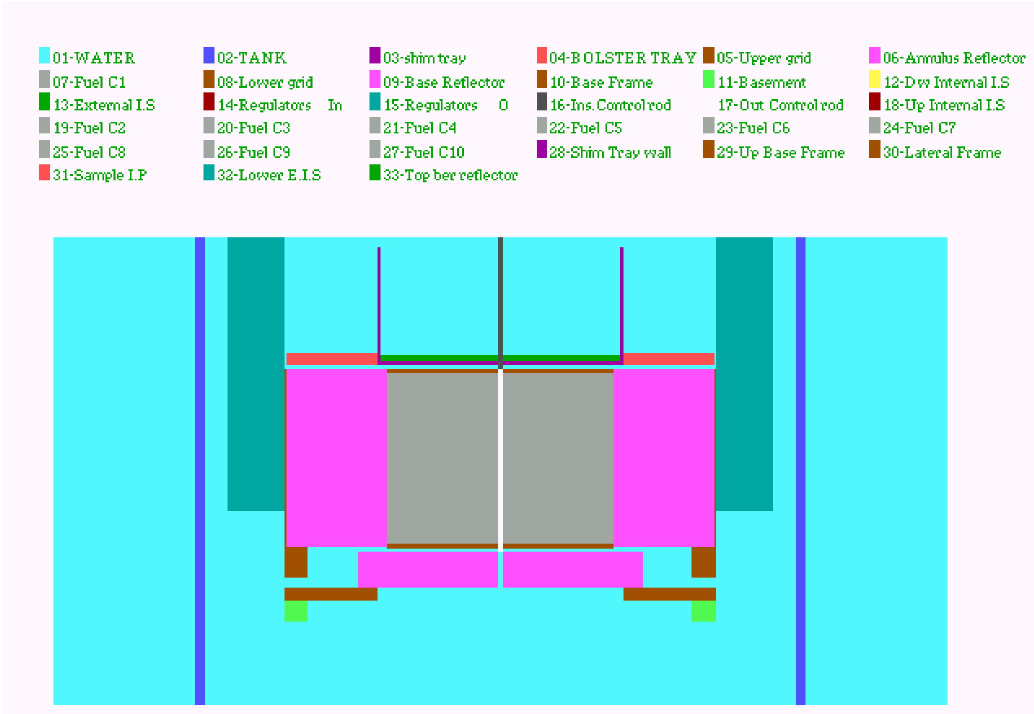
3.Some Heat Transfer and Thermohydraulic Considerations

It is well known that the mechanism of heat transfer in the core of the reactor is the natural convection [8], it would be of great importance to see if this mechanism is still sufficient in the case a mixed fuel (some fuel rods are HEU and others are LEU ones).
Since the power of a fuel rod at the nominal power of the reactor is somehow around 85 W in average, it is expected that the thermal hydraulic consequences of mixing the fuel would not be of high relevance.
Tables 1, 2, 3 in fact show the maximum temperatures of the channels of the core and the total generated heat in the channel
Compared to the reference case, the maximum temperature differences are limited to about ±7-9%.

4.Results and Discussion

In this paper some of the MNSR neutronic and thermohydraulic characteristics were investigated using a 3-D neutronic model and a thermohydraulic code. It seems really that conversion of this reactor, up to a certain extent, does not raise particular thermohydraulic problems, because the maximum temperatures in the core channels are fairly below the fuel melting point. This applies if the fuel is used in the dispersed form.
From the neutronic point of view, it seems evident from Tables 1,2 and 3 that even if we can operate the reactor with fresh fuel combining LEU and HEU fuels, the reactor may not operate for a long time because of the absence of reactivity recovery after the initial excess reactivity has degraded up to the point the reactor cannot work. In this case there are no means to recover the consumed reactivity,

because the Shim Tray is completely filled with the Top Beryllium Shims (see Fig. 2).



Axial representation of the reactor for sector No. 1 (at 12.22 degrees)

Figure(2) A schematic axial representation of the Syrian MNSR.

This suggests probably to move to denser fuels. The choice of the new fuel will depend on the results of extensive calculations to verify the economical convenience of the choice. So it is expected that a good job is still awaiting to be performed.

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